Vegetation landscape structure and dynamics in sandy forest-steppe ecotone

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Abstract: Sandy forest-steppe ecotone in Baiyinaobao Natural Reserve of Inner Mongolia Autonomous Region of China is one of the special landscape types in forest-steppe vegetation zone in China. Vegetation landscape types, landscape patches, and patch size were measured by the field investigation, forest photograph, and airscape. The structure of landscape patches in sandy forest-steppe ecotone, including composition structure, and size structure, was studied and the dynamics and transformation of landscape patches were analyzed. The data obtained in this study could provide theoretical basis for the research on vegetation landscape in forest-steppe ecotones and other vegetation types.

Keywords: Vegetation landscape; Structure; dynamics; Sandy forest; Steppe; Ecotone

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Introduction

In recent years, many ecologists have shown their research interests in ecotones between or among two or more vegetation types (Boren *et al.* 1997, Milne *et al.* 1996, Bowman 1993), for example, between forest and grassland (Dyer *et al.* 1997), forest and savanna (Fensham *et al.* 1992), forest and swamp (Carter *et al.* 1994), and so on. In China, a few of ecologists always understood ecotone as a transitional zone (Xu *et al.* 1998). Until 1980's, ecotone was reemphasized by ecologists with the development of ecology and uprising of landscape ecology. Sandy forest-steppe ecotone in Baiyinaobao Natural Reserve of Inner Mongolia Autonomous Region in China is one of the special landscape types, and is a very important research project (Xu *et al.* 1993). The objective of this study is to provide scientific basis for the further researches on sandy forest-steppe ecotones and ecological construction in process of western development in China.

Study site and method

The study was conducted in Baiyinaobao Natural Reserve (43°30'-43°36' N, and 117°06'-117°16' E), the eastern Inner Mongolia Autonomous Region, China. This area lies in the transitional region from Daxing'an Mountains to Mongolia Plateau, with characteristics of typical temperate continent steppe climate, and was a typical sandy forest-steppe ecotone. Annual mean temperature is -1.4 °C. Minimum mean temperature is -23.4 °C in Januaryand the maximum is 14.7 °C in July. Annual average rainfall was 448.9 mm. The potential evaporation was 1 526 mm.

Vegetation landscape types, landscape patches, and patch size were measured by the field investigation, forest photograph, and airscape.

Results

Vegetation landscape types

Forest landscape types: The main forest landscape was *Picea mongolica* forest, which could be divided into two types. (1) Moss-*Carex* spp.-*Picea mongolica* forest. It was a typical forest type in the region distributing in the shady side, semi-shade side of dunes, and meadow between dunes in small patches. For this type of forest, dominant tree species is *P. mongolica*, accompanied with *Betula platyphylla, Populus davidiana, Ulmus pumila,* and so on. Under the forest there are a few shrub species, such as *Cotoneaster melanocarpus, Ribes diacanthum*, and in herb layer *Carex lanceolata* was the dominant species. The moss layer developed very well and fully covered the soil surface, with the thickness of 7-10 cm. The main species in moss layer are *Phytidium rugosum, Phytidiadphs trguetrus.* (2) Herb-grass *Picea mongolica* forest, which was distributed mainly on the top of dunes and slow-waving sandy land. Its shrub layer is sparse andmainly composed of *Prunus padus, Spiraea* spp, *Cotoneaster melanocarpus*, while herb and moss layers are uneven. In southern side of trees, the main species in herb layer were basically steppe composition, such as *Leymus chinensis, Agropyron cristatum, Siler divaricatum, Hedysarum fruticosum, Scabio isetensis*, but in northern side of trees, there are some

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shade-tolerant species due to soil moisture condition, such as *Patrinia repestris, Viola variegata*, and so on. Moreover, there are also *Betula platyphylla* forest, *Populus davidiana* forest, and *Ulmus pumila* sparse forest.

Steppe landscape types: The main steppe landscape is xeric herb-grass-steppe, distributing in the sunny side of dunes, top of dunes and slow-waving sandy land. The main edificators were *Koeleria cristata, Cleistogtues squrrosa, Festuca dahurica,* etc.. Furthermore, grass layer developed very well. In steppe vegetation, *Calium verum, Scabiosa isetensis* are sub-edificators, and there were other species with high frequency, such as *Potentilla acaulis, Potentilla chinensis, Veronica incana.* Moreover, many companion-person and toxic plants were found, such as *Stellera chamijasme, Messerschmidia sibirica,* and so on.

Vegetation landscape structure

Patches composition

The obvious characteristic of sandy forest-steppe ecotone was coexistence and alteration of forest landscape and steppe landscape. The data of ecosystem types, number of patches, and the area of patches were shown in Table 1.

Table 1. Patches composition of sandy forest-steppe landscape

Type of Patches	Number of patches		Area of patches	
	Number	%	Area /hm^2	%
MCPMF	26	13.33	361.40	6.32
HGPMF	16	8.21	839.50	14.69
BPF	14	7.18	200.80	3.51
PDF	27	13.85	265.10	4.64
UPSF	8	4.10	170.10	2.98
Shrub	25	12.82	656.80	11.49
Sandy steppe	63	32.31	2607.00	45.62
Sandy meadow	10	5.13	540.60	9.46
Swamp	2	1.03	25.00	0.44
Farmland	4	2.04	48.20	0.84
Sum	195	100.00	5714.50	100.00

Note: MCPMF: Moss-*Carex* spp.-*Picea mongolica* forest, HGPMF: Herb-grass-*Picea mongolica* forest, BPF: *Betula platyphylla* forest, PDF: *Populus davidiana* forest, and UPSF: *Ulmus pumila* sparse forest. **Those abbreviations have the same meaning for Table 2, 3 and 4.**

Based on the Table 1, we can see that the sandy steppe is main vegetation type of sandy forest-steppe landscape accounting for 32% of the total number of patches and 45% of the total area of patches in Baiyinaobao Natural Reserve. The main dominant species are *Agropyron cristatum, Koeleria cristata* in sandy land, and accompanied with other grasses species, such as *Calium verum, Potentilla acaulis, Allium tenuissimum.* The vegetation was always replaced by *Artemisia frigida* steppe and *Polygomum divaricatum* steppe under human activities. The area of sandy meadow is very small, accounting for 9%, and mainly distributed on low-lying land and riverbank.

Forest area accounted for 32% of the total area of patches and 47% of the total number of patches in Baiyinaobao Natural Reserve. Sandy forest is located in steppe background in small patches. For forest landscape, *Picea mongolica* forest accounted for 65% of the area of forest landscape. Patches of *Betula platyphylla* forest and *Populus davidiana* forest accounted for 7% in area, about 21% in number, so these tow species had more frequency in sandy steppe matrix. *Ulmus pumila* sparse forest is also an important composition of sandy forest-steppe ecotone, though its patches' number (4%) and area (2%) is small. Shrub patches that developed very well are important landscapes of sandy forest-steppe ecotone, accounting for 13% of the total patch number and 11% of the total area of patches, mainly distributing along riverbank in corridors. Moreover, there are also some swamp and agricultural fields, but the percentage of area was less than 1.

Patch size

Patch size is the area of vegetation types. Landscape formation in sandy land had a close relationship with sandy site conditions. Sandy forest is distributed mainly on the shady side of dunes and slow-waving sandy land, steppe vegetation mainly on the sunny side of dunes, and meadow vegetation mainly on low-lying land among dunes.

The mean patch size of sandy steppe, sandy meadow, and herb-grass-*Picea mongolica* forest patches is 53.80, 54.20, and 52.50 hm^2, respectively (Table 2). Moss-*Carex* spp.-*Picea mongolica* forest was main vegetation in sandy forest-steppe landscape, though its mean patch area was small (Xu *et al.* 1998).

Table 2. Patch size of sandy forest-steppe landscape /hm^2

Patches types	Patch size		
	Maximum /hm^2	Minimum /hm^2	Mean /hm^2
MCPMF	58.30	2.10	13.80
HGPMF	387.50	4.20	52.50
BPF	47.10	2.50	34.50
PDF	91.70	2.10	10.00
UPSF	42.50	5.00	21.30
Shrub	157.90	2.10	26.30
Sandy steppe	239.60	1.70	53.80
Sandy meadow	123.80	7.50	54.20
Swamp	15.00	10.00	12.50
Farmland	20.80	5.40	12.10

As far as main vegetation type patches was concerned, small patches and middle patches in size were more than 50%, and big patches more than 50 hm^2 in area only took up 10% (Table 3). As to forest landscape, small patches were more common, followed by middle patches, excluding *Ulmus pumila* sparse forest. For steppe vegetation landscape, middle patches took up 54%, and comprised basic sandy forest-steppe landscape.

Table 3. Quantity allocation of various sandy forest-steppe patches

Patches types	Small patch (<10 hm^2)	Middle patch (10-50 $hm^{2)}$	Large patch (50-100 hm^2)	Extreme large patch (100-200 hm^2)	Huge patch (>200 hm^2)	Sum
MCPMF	17 (65.38)	8 (30.77)	1 (3.85)	0 (0.00)	0 (0.00)	26
HGPMF	7 (43.75)	6 (37.50)	1 (6.25)	1 (6.25)	1 (6.25)	16
BPF	8 (57.14)	6 (42.86)	0 (0.00)	0 (0.00)	0 (0.00)	14
PDF	22 (81.48)	4 (14.81)	1 (3.70)	0 (0.00)	0 (0.00)	27
UPSF	2 (25.00)	6 (75.00)	0 (0.00)	0 (0.00)	0 (0.00)	8
Shrub	15 (60.00)	5 (20.00)	3 (12.00)	2 (8.00)	0 (0.00)	25
Sandy steppe	14 (22.22)	34 (53.97)	7 (11.11)	7 (11.11)	1 (1.59)	63
Sandy meadow	2 (20.00)	4 (40.00)	2 (20.00)	2 (20.00)	0 (0.00)	10
Swamp	1 (50.00)	1 (50.00)	0 (0.00)	0 (0.00)	0 (0.00)	2
Farmland	2 (50.00)	2 (50.00)	0 (0.00)	0 (0.00)	0 (0.00)	4

Note: Data in the parenthesis are percentage.

As to patch area (Table 4), in forest landscape, there were many middle patches and small patches, except for herb-grass-*Picea mongolica* forest. There were no extreme large patches of (100-200 hm^2) and huge patches (>200 hm^2) for Moss-*Carex* spp.-*Picea mongolica* forest, *Populus davidiana* forest, *Betula platyphylla* forest, and *Ulmus pumila* sparse forest. However, herb-grass-*Picea mongolica* forest was very special and its huge patches took up 46%.

Extreme large patches had a bigger ratio in shrub, sandy meadow, and sandy steppe landscapes. In sandy steppe vegetation, huge patches were more than 9%. Generally speaking, variation of patch area was smaller than that of number.

Table 4. Area allocation of sandy forest-steppe patches

Patches types	Small patch (<10 hm^2) /hm^2	Middle patch (10-50 hm^2) /hm^2	Large patch (50-100 hm^2) /hm^2	Extreme large patch (100-200 hm^2) /hm^2	Huge patch (>200 hm^2) /hm^2	Sum /hm^2
MCPMF	69.70 (19.29)	233.40 (64.58)	58.30 (16.13)	0.00 (0.00)	0.00 (0.00)	361.40
HGPMF	53.40 (6.36)	125.30 (14.92)	95.40 (11.36)	177.90 (21.19)	387.50 (46.16)	839.50
BPF	28.70 (14.29)	172.10 (85.71)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	200.80
PDF	108.00 (40.74)	65.40 (24.67)	91.70 (34.59)	0.00 (0.00)	0.00 (0.00)	265.10
UPSF	11.70 (6.88)	158.40 (93.12)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	170.10
Shrub	70.10 (10.67)	86.30 (13.14)	208.30 (31.71)	292.10 (44.47)	0.00 (0.00)	656.80
Sandy steppe	55.10 (2.11)	859.00 (32.94)	453.70 (17.40)	999.60 (38.33)	239.60 (9.19)	2607.00
Sandy meadow	15.40 (2.85)	132.20 (24.45)	168.80 (31.22)	224.20 (41.47)	0.00 (0.00)	540.60
Swamp	10.00 (40.00)	15.00 (60.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	25.00
Farmland	11.60 (24.07)	36.60 (75.93)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	48.20
Sum	433.70 (7.59)	1883.70 (32.95)	1076.20 (18.82)	1693.80 (29.62)	627.10 (10.97)	5714.50

Note: Data in the parenthesis are percentage of ratio

Vegetation landscape dynamics

In the ecotone, forest landscape series and steppe landscape series could transform each other during succession stages of some patches. This transformation included two types: forest process and steppe process.

Forest process

Picea mongolica forest process resulted from the succession stages of different vegetation types with the change of matrix in vegetation.

(1) Patches stage of sandy pioneer vegetation: When sandy land was in the flowing state, some sandy pioneer species invaded rapidly, such as some annual or biennial herb species, *Agriophyllum squarrosum, Corispermum* spp., and so on. These species also had intensive adaptability, in terms of more seed production, shallow root system, and global body. The seeds of these species dispersed with wind, and bud grew rapidly when the environment conditions were suited. And then some big sandy plants invaded, such as *Polygomum divaricatum, Artemisia intramongolica,* and became perennial herb-grass vegetation patches with the decrease of number and growth of pioneer species. *Salix flavida* shrub patch was also one of sandy vegetation patches, and it was a special pioneer plant patch. The vegetation was found in the shady side of dunes or low-lying land among dunes. *Salix flavida* shrub patches were taken place by rhizoma herb-grass vegetation patches, after transformation of sandy matrix from flowing dunes to stable dunes during post stage of *Salix flavida* shrub patch.

(2) Patches stage of rhizoma herb-grass vegetation: Sandy matrix became denser and denser due to the effects of vegetation patches on flowing dunes. Moreover, the soil nutrients became richer, and the soil moisture became worse with the rapid soil formation process. Under this circumstance, some drought-tolerant perennial rhizoma herb-grass species invaded. These species included *Leymus chinensis, Agropyron cristatum, Hedysarum fruticosum, Bupleurum scorzonerifolium,* and so on, and gradually came into being various kinds of stable sandy steppe patches, such as *Leymus chinensis* steppe patches, *Agro-*

pyron cristatum steppe patches, *Koeleria cristata* steppe patches.

(3) *Picea mongolica* forest patches stage: Landscape transformation was caused because of landform heterogeneity. It was generally divided into two ways. One is that in the shady side or semi-shady side of dunes, the landscape transformed from rhizoma herb-grass-steppe patches to shrub patches, such as *Cotoneaster melanocarpus* shrub patches, *Prunus padus* shrub patches, *Ostryopsis davidiana* shrub patches, and so on, finally to climax vegetation -moss-*Carex* spp.-*Picea mongolica* forest patches. The other is that in the sunny side or top of dunes or slow-waving sandy land, the landscape transformed from rhizoma herb-grass-steppe patches to drought-tolerant shrub patches, such as *Spiraea* spp shrub patch, *Prunus sibirica* shrub patches, finally to herb-grass-*Picea mongolica* forest patches.

Steppe process

There were two kinds of secondary vegetation patches with different habitat conditions after *Picea mongolica* forest being destroyed. One was from *Picea mongolica* forest patches to *Populus-Betula* forest patches in the shady side of dunes, and the other was from *Picea mongolica* forest patches to steppe patches. 70% of sandy steppe in Baiyinaobao Natural Reserve was dominated by the secondary steppe landscape after *Picea mongolica* forest was destroyed.

Discussion

How did the vegetation landscape patches form in sandy forest-steppe ecotone? There are maybe the following three causes.

Climate: The distribution range of Picea-Abies forest in Northeast China according to Kira's warmth index (WI) was constant, with a range of 20-45 °C·month no matter what location and altitude. WI value of *Picea mongolica* forest was 25.1-41.1℃·month. This showed that temperature was not limiting factor for growth and distribution of *Picea mongolica* forest in Baiyinaobao Natural Reserve. According to research on relationship between main vegetation landscape and humidity index (HI) in western area of China, HI value of forest distribution in China was in range of 7.5-15.5 mm / ℃·month (Xu 1985, 1993; Xu *et al.* 1992). Humidity index of Baiyinaobao Natural Reserve was 7.1 mm / ℃·month. This area was just located in forest-steppe ecotone. HI value for Picea-Abies forest was in range of 7.7-11.5 mm / ℃·month, thus it is obvious that HI value was the limiting factor for Picea-Abies forest distribution in Baiyinaobao Natural Reserve. Therefore, it is impossible that there are many forest landscapes in sandy forest-steppe ecotone. In the shady side of dunes, there are forest patches for better moisture condition.

Landform: Differences of slope location and slope direction led to reallocation of moisture and temperature conditions. In the shady side of dunes, the temperature is lower, the relative humidity is higher, and the potential evaporation is small. Thus *Picea mongolica* forest, *Betula platyphylla* forest, and *Populus davidiana* forest mainly distribute on here. However, on the sunny side or the top of dunes, the maximum temperature of surface is 45.7℃ in July, and this can make many plants suffer hot damage, including *Picea mongolica* seedlings.

Human activities: Fragmentation of sandy forest-steppe landscape mainly resulted from forest fire and overgrazing in steppe, and these disturbances made the forest patches and steppe patches become smaller and smaller in size, and more and more in number. According to historical records, before liberation of China in 1949, local people took *Picea mongolica* as "saint tree" and protected it in Baiyinaobao Region. Therefore, at that time forest area was much larger than now, and was named "thousands miles of pine forest". However, in 1952 and 1960, two forest fires destroyed more than 70% of the forest, which led to the transformation of primary *Picea mongolica* forest to sparse forest. At the same time, large area of secondary sandy steppe vegetation came into being after steppe process of shrub and meadow.

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